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Spin transfer to Λ_c^+ hyperons in polarized proton collisions at RHIC

V. L. RYKOV and K. SUDOH

RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan
E-mails: rykov@riken.jp, sudou@rarfaxp.riken.jp

The analysis[1] of helicity transfer to Λ_c^+ in polarized proton collisions is extended to the proton helicity correlations with the Λ_c^+ transverse polarization in the production plane (parameter D_{LS}). The available spin transfer observables for the collisions of *two* longitudinally polarized protons are evaluated. It is shown that, in the central region at Λ_c^+ transverse momenta of a few GeV/c, D_{LS} parameters are of about the same size as the helicity-to-helicity correlations. The methodical issue of using spin transfers for cross-checks of systematic errors in cross-section A_{LL} measurements at polarized proton colliders is also briefly discussed.

1 Introduction

Spin transfers to inclusive strange and charmed hyperons in polarized proton collisions have been recently proposed[1, 2] as a probe for the polarized gluon distribution $\Delta G/G$ of proton. Compared to the usually considered for this purpose cross-section asymmetry $A_{LL} = \frac{\sigma^{++}-\sigma^{+-}}{\sigma^{++}+\sigma^{+-}}$, where σ^{++} and σ^{+-} are the cross sections for same and opposite helicities of colliding protons, spin transfers are linear with $\Delta G/G$ while $A_{LL} \propto (\Delta G/G)^2$. This means that spin transfers might become more sensitive probes for polarized gluon distribution if $\Delta G/G$ appeared to be small. The other difference is that, unlike A_{LL}, spin transfer measurements generally do not require monitoring the relative luminosity of collisions with different polarizations of initial protons. Such monitoring is not a simple task at a proton collider with longitudinally polarized beams and is always considered as a potential source of systematic errors. And, in general, measuring a number of sensitive characteristics rather than one and comparing them to the predictions of theoretical models could serve as a good consistency check of the model's assumption.

In the papers[1], the measurements of helicity-to-helicity transfer parameter D_{LL} in gluon fusion dominant Λ_c^+ production at RHIC with polarized protons have been proposed and studied[1]. In this report, we extended this analysis

[1]The notation A_{LL} has been used for D_{LL} in Refs[1].

to the proton helicity correlations with the Λ_c^+ transverse polarization in the production plane (parameter D_{LS})[2]. The D_{LS} is also expected to be nonzero at Λ_c^+ transverse momenta (P_T) of a few GeV/c due to the large c-quark mass. Moreover, for each spin transfer, LL and LS, we evaluated two more observables: $D_{L\Pi}^{++}$ and $D_{L\Pi}^{+-}$, $\Pi = L, S$, which will be measured at RHIC in collisions of *two* polarized protons of the same and opposite helicities:

$$\begin{aligned} D_{L\Pi}^{++} &= \frac{\sigma_{L\Pi}^{++;+} - \sigma_{L\Pi}^{++;-} - \sigma_{L\Pi}^{--;+} + \sigma_{L\Pi}^{--;-}}{\sigma^{++;+} + \sigma^{++;-} + \sigma_{L\Pi}^{--;+} + \sigma_{L\Pi}^{--;-}}\,, \\ D_{L\Pi}^{+-} &= \frac{\sigma_{L\Pi}^{+-;+} - \sigma_{L\Pi}^{+-;-} - \sigma_{L\Pi}^{-+;+} + \sigma_{L\Pi}^{-+;-}}{\sigma_{L\Pi}^{+-;+} + \sigma_{L\Pi}^{+-;-} + \sigma_{L\Pi}^{-+;+} + \sigma_{L\Pi}^{-+;-}}\,, \quad \Pi = L, S \end{aligned} \tag{1}$$

In Eqs. (1), $\sigma_{LS}^{--;+}$, for example, is for the production cross-section of Λ_c^+ with the polarization "+1" along the S-axis in the collisions of two proton beams, both of the *negative* helicity equal to "-1".

Parameters $D_{L\Pi}$ for collisions of polarized protons at unpolarized are the weighted with A_{LL} averages of $D_{L\Pi}^{++}$ and $D_{L\Pi}^{+-}$:

$$D_{L\Pi} = \frac{1}{2}[D_{L\Pi}^{++}(1 + A_{LL}) + D_{L\Pi}^{+-}(1 - A_{LL})] \tag{2}$$

In turn, if all three D's for the same final spin component were measured, then A_{LL} can be derived, using Eq. (2). As it mentioned above, the A_{LL} determined this way would potentially be free from systematics due to monitoring the relative luminosity of collisions with different beam polarizations. With this approach, the statistical error $\delta A_{LL} \approx \frac{2\sqrt{6}}{\alpha P |D_{L\Pi}| \sqrt{N}}$, where α is the hyperon decay asymmetry parameters; P is the beam polarization; N is the combined statistics in 3 measurements. This error would usually be noticeably larger than of "direct" A_{LL} measurements. However, if the systematic rather than statistic is an issue, then using spin transfers in high event rate processes, along with Eq. (2), could be an option.

2 Numerical results and discussion

The leading order calculations for pseudo-rapidity dependences of 6 spin transfer parameters, averaged over P_T interval from 2 to 5 GeV/c, are shown in Fig. 1. These results have been obtained, using the same assumptions as in the analyses[1]. Only the dominant partonic subprocess of gluon fusion, $gg \to c\overline{c}$, was taken into account. The same spin dependent fragmentation function $\Delta\mathcal{D}(z) = \mathcal{C}(z) \cdot \mathcal{D}(z)$ were used for both the longitudinal and transverse spin transfers from c-quark to Λ_c^+, where $\mathcal{D}(z)$ is the "unpolarized" quark fragmentation function. For the $\mathcal{C}(z)$, two options are compared: $\mathcal{C}(z) = 1$ and $\mathcal{C}(z) = z$. The shown statistical errors are for the integrated luminosity of 320 pb^{-1} and beam polarization of 70%, assuming that the decay chain $\Lambda_c^+ \to \Lambda^0\pi^+ \to p\pi^-\pi^+$

[2] L and S axes here correspond to Z and X in the notations of book[3].

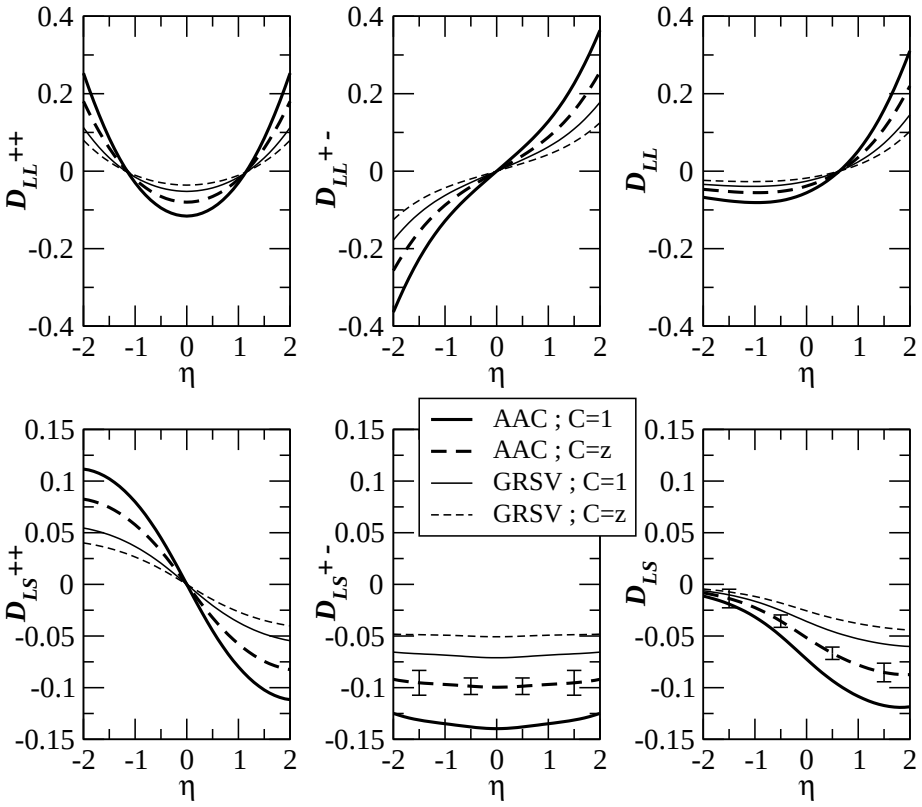

Figure 1: η-dependences of spin transfer parameters for inclusive Λ_c^+ production in polarized proton collisions at $\sqrt{S}$= 200 GeV. The leading order predictions for AAC[4] and $GRSV$[5] polarized gluon distributions are compared. Each error bar is for the integrated statistics within a pseudo-rapidity interval of $\Delta\eta = 1$. See text for other details.

is to be used for measuring the Λ_c^+ polarization, with the detection efficiency at $\sim$10%.

In the central region of $|\eta| < 1$, D_{LL}'s and D_{LS}'s are of about the same size in the range of $\sim$5–15%. As η increases, all D_{LL}'s grow up to $\sim$20–30% at $\eta \sim 2$ for the AAC parameterization[4], while D_{LS}^{+-} stays almost flat. The achievable statistical errors of about 1% are small enough to clearly separate predictions for the shown models even in the central rapidity region. Since only a half of the total luminosity will be utilized for measuring $D_{L\Pi}^{++}$, and the other half will go to the measurements of $D_{L\Pi}^{+-}$, the statistical errors for these parameters would be larger than for $D_{L\Pi}$ by a factor of $\sqrt{2}$. However, it is worth underlining that $D_{LL}^{++} \approx 2D_{LL}$ and $D_{LS}^{+-} \approx 2D_{LS}$ for η in the vicinity of zero. These relations follow from Eq. (2) with $|A_{LL}| \ll 1$, and taking into account the "forward–backward" symmetry of the initial system of two colliding protons. As

a result, in the central region, the statistical significance of measurements with two polarized beams would be higher compared to the case of only one beam being polarized.

3 Summary

It is shown that both components, D_{LL} and D_{LS}, of the proton helicity transfer to the polarization of inclusive Λ_c^+ hyperons are expected to be equally sensitive to $\Delta G/G$. In the central region, the expected effects at $\sim$5–15% are well above the achievable at RHIC statistical errors, which are also small enough for distinguishing the AAC[4] and $GRSV$[5] parameterizations for $\Delta G/G$. The really large spin transfers at the level of up to 20–30% are expected at $\eta \sim 2$ and beyond, which could be potentially accessible at STAR[6], but definitely with the recently proposed new RHIC-II detector[7].

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